What Ocean Systems Affect Our Planet's Climate?

Earth's climate is the result of interaction of many physical environmental systems. These systems transport heat, air, and water around Earth. Their steady rhythmic flow ensures a relatively stable climate. Heat transport by global ocean currents is a relatively stable interaction between the ocean-atmosphere system. Rhythmic changes of heating and cooling over Asia lead to the rhythm of the *monsoons*. However, some of the more intriguing components of climate are associated with instability in the system, *El Niño* and hurricanes, for example. Understanding these systems and their interactions is fundamental to the study of climate.

This theme (*Climate - Systems and Interactions*) addresses the heat transported by the *global conveyor belt* model. It also addresses specific ocean-related climate components such as monsoons, El Niño, and hurricanes.

Related Themes:

- Climate during the ice ages is described in *Climate - Process and Change.*
- The El Niño phenomenon is examined in *Oceans - Process and Change*.
- Using satellites to study climate systems is discussed in *Climate - Measurements*.
- How salinity, temperature, density, and pressure affect the oceans' vertical structure is featured in the *Oceans - Scale and Structure*.
- Coastal upwelling is addressed in the *Oceans - Systems and Interactions*.
- The Coriolis Effect is explained in the *Oceans - Energy*.

Related Activities:

- *Temperature and Ocean Circulation*
- *Salinity and Ocean Currents*
- *Message in a Bottle*

Introduction

A *system* is defined as a regularly interacting or interdependent group of elements forming a unified whole. Earth's climate is the result of a global environmental system, a regularly interacting, interdependent group of sub-systems forming a unified whole. For example, by looking down at Earth from satellites, scientists can study how subsystems interact to produce our global systems. There are many climate systems on Earth and they are often large and fast changing. The ocean is an important driver in many of those systems.

Because Earth is round, it is heated unevenly by sunlight. The equator is much hotter than the poles because light from the Sun strikes Earth more directly at the equator. At higher latitudes the Sun's energy striking Earth is spread over a larger area [Fig. 1]. Solar heating is one element or subsystem of the global system.

Heat is redistributed from equatorial regions to the poles by both the atmosphere and the ocean. Interestingly, the upper 3 meters of the ocean stores the same amount of heat as all of the atmosphere. The heat transport of North Atlantic alone is 100 times all man-made energy production. The atmosphere (wind) and ocean systems each deliver about half the heat trans-

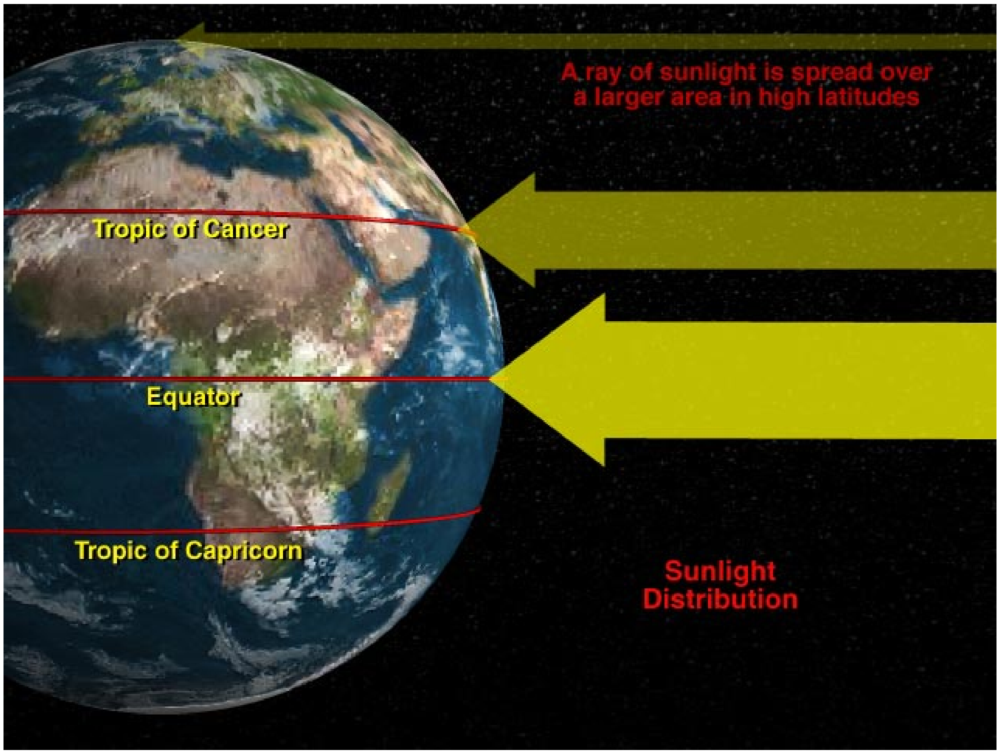


Figure 1. **Sunlight striking Earth**. Sunlight is spread out over larger areas at the poles, making energy deposition much less efficient.

ported from the equator to the poles. The transport of heat is another element or subsystem of the global system.

Some of the atmospheric heat transport occurs via *Hadley cells*. Over the equator, hot air rises and moves northward and southward. The air cools as it moves away from the equator, eventually becoming dense enough to sink again. Then air moves back toward the equator at lower altitudes. This has the effect of moving heat towards the poles of Earth.

The Global Conveyor Belt

The *global conveyor belt* is the major element or subsystem that carries heat in the ocean. It is a simplified model of how heat is transported from the tropics to the far North Atlantic. The global conveyor belt circulates warm water from tropical and subtropical regions toward the polar regions, where it surrenders heat to the atmosphere, cools and sinks, and flows back towards the equator [Fig. 2].

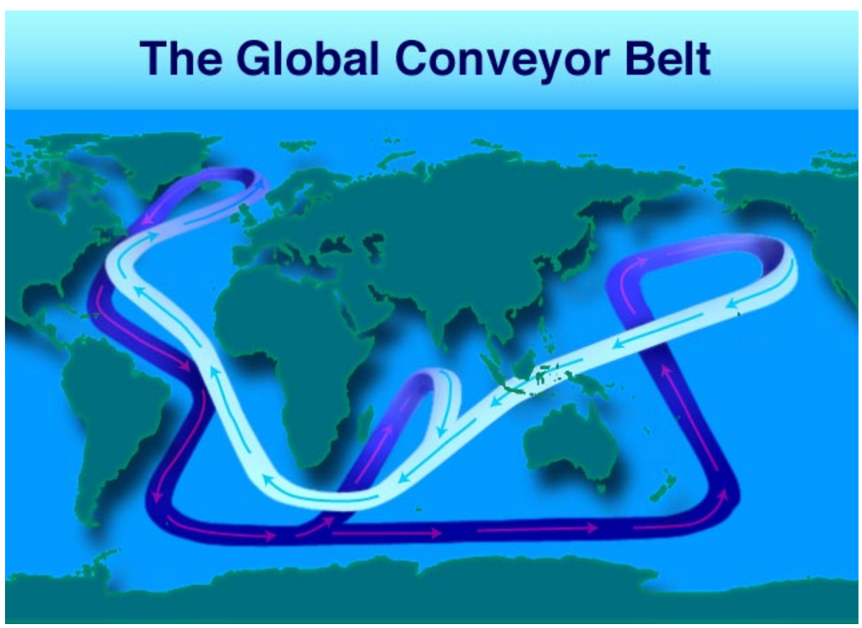


Figure 2. **Global Conveyor Belt**. Schematic showing the flow of water as part of the Global Conveyor Belt, which redistributes energy from the equatorial regions to the poles.

During winter in the North Atlantic, cold fronts carry dry Arctic air over the ocean. This removes heat and evaporates water, cooling the ocean surface and making it saltier (because the salt does not evaporate). Both of these effects make the water denser, causing it to sink. Layers of sea water sink until they encounter layers of similar or higher density. Because the Atlantic is the saltiest ocean, the cold salty water formed in winter sinks all the way to the bottom of the ocean. It then flows south at depth, forming the Atlantic deep-water current, which transports more than 20 times more water than all of the world's rivers combined. The current eventually travels east past Africa where some of it rises in the Indian ocean, and some makes it all the way to the northern Pacific. Now warmer and less salty, it migrates at shallower depths back towards the North Atlantic. The driving force is global *upwelling* through the *thermocline*.

Scientists have found that changes in the amount of heat transported by the conveyer belt are significant in controlling Earth's climate, particularly in the northern hemisphere. When large amounts of water in the North Atlantic sink quickly, the process transports more heat. If this global conveyor belt shuts down - for example if fresh water flow from polar ice prevents the sinking of water in the North Atlantic - then drastic climate changes, including the onset of another *ice age*, may occur. Thus, it is important to understand this complex yet critical link in global climate.

The rate at which water sinks in the north is controlled by the ocean's salt content or *salinity*. Colder water is denser than warm water and saltier water is more dense than fresh water. If the water is too fresh (i.e. not very salty), it is not heavy enough to sink. In the global conveyer belt process, salinity is controlled by evaporation and precipitation, melting and the formation of sea ice at high latitudes. These processes are all interrelated, making the global conveyor belt a very complex system and one prone to instabilities and rapid changes.

Monsoons

Differences in the *heat capacity* of land and water can influence local weather by controlling the direction of sea breezes. Similarly, larger-scale interaction between the ocean, land, and atmospheric systems produce highly stable and predictable seasonal changes in winds called monsoons.

Heat capacity is the amount of heat required to raise the temperature of 1 gram of any substance by 1°C. The difference in heat capacities of ocean water (relatively high) and continental rocks (relatively low) is illustrated in Figure 3. As the Sun beats down on many of the world's coasts, the water absorbs heat, but its temperature does not change by more than a couple of degrees. Meanwhile the land gets warmer and warmer and its temperature rises by tens of degrees Fahrenheit like a brick in an oven. At night, the land cools, but the water does not. A good way to demonstrate this is on a hot summer day. The next time you get to a beach, just walk from your towel to the water with bare feet. Repeat the experiment after the Sun has set. The sand on the beach will be noticeably cooler, but the water will be about the same temperature.

Monsoon is an Arabic word meaning seasonal winds. It was first applied to the winds over the Arabian Sea, which blow six months of the year from the northeast, and the remaining six months from the southwest. These seasonal changes are most obvious in the northern Indian Ocean.

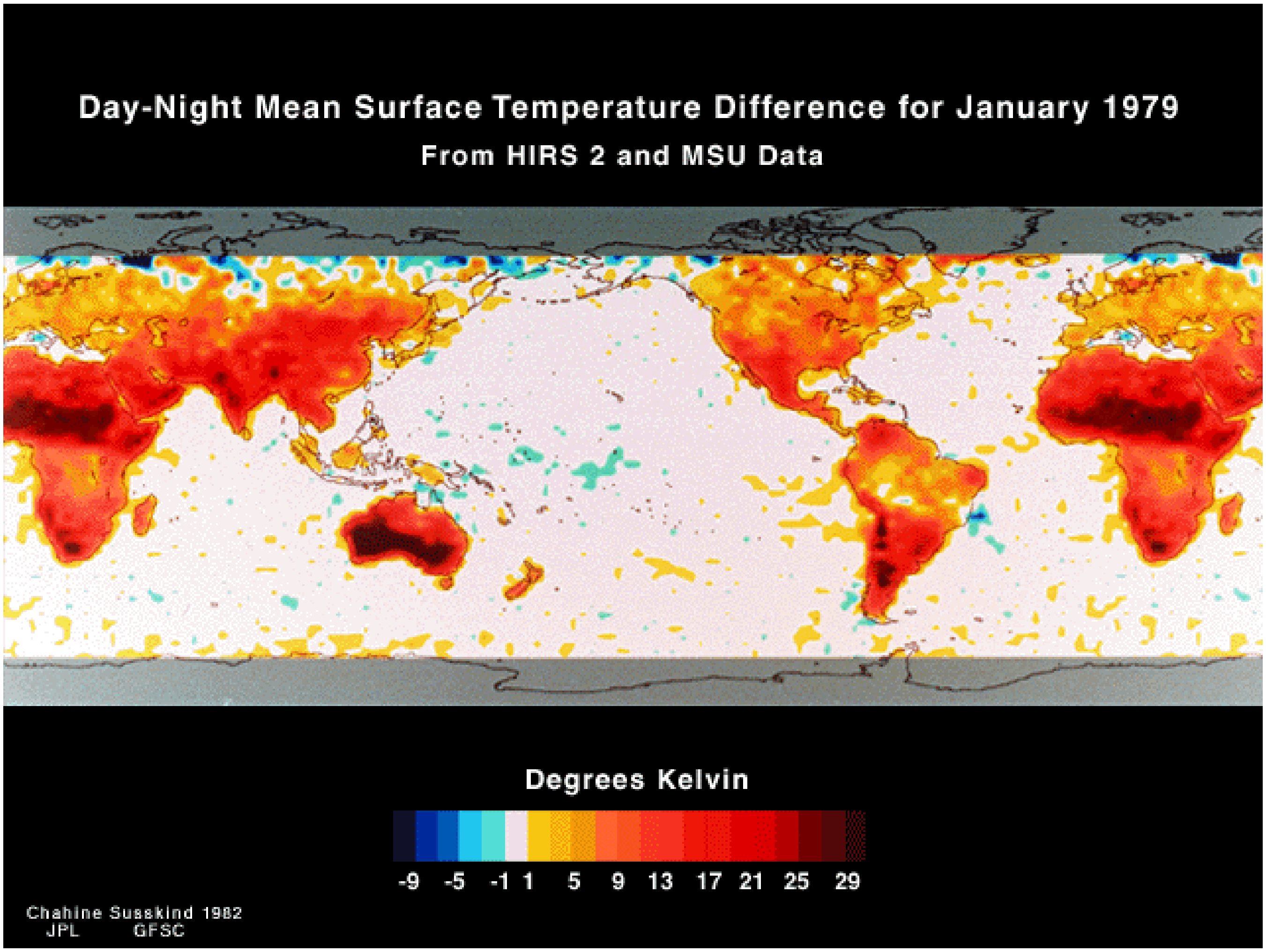


Figure 3**. Day and night temperature differences**. This map shows the difference between day and night temperatures, averaged for the month of January 1979. In the white areas of open ocean, there is only a 1°C difference in day and night temperatures. On the other hand, changes in day-to-night temperatures in Asia are generally greater than 15°C. This dramatically demonstrates the difference in heat capacity between water and land.

During the summer throughout Asia, the warm land causes air to rise over the continent. These vertical air motions draw cooler, moisture-rich winds inland from the ocean As this onshore flow rises over the continent, it produces heavy monsoon rains. A similar process occurs in southern Arizona during the summer. Moist waters from the Gulf Coast and Gulf of California flow over the southwestern desert, bringing with it seasonal winds and rain.

In winter the winds reverse. Cold air from the continent is drawn seaward by relatively warm air rising over the ocean. This produces cool, dry weather known as the winter monsoon. For centuries, sailors of the northern Indian Ocean have depended on these seasonal wind reversals to carry them back and forth on trading expeditions between India and Africa.

El Niño

The oceans play a dominating role in year-to-year variability that dramatically impacts weather and climate. One example of this is the well-known El Niño phenomenon.

El Niño causes warm water currents to appear along the west coast of South America, resulting in unusual warming of the eastern tropical Pacific. The name El Niño (Spanish for "boy child") was coined by a late 15th century Spanish fisherman who first documented the warm current off Peru's west coast around Christmas-time. In recent years, the rest of the world has adopted the term El Niño to describe conditions when warm water occupies much of eastern equatorial Pacific [Fig. 4], affecting the path of the atmospheric *jet stream* and altering weather patterns around the globe.

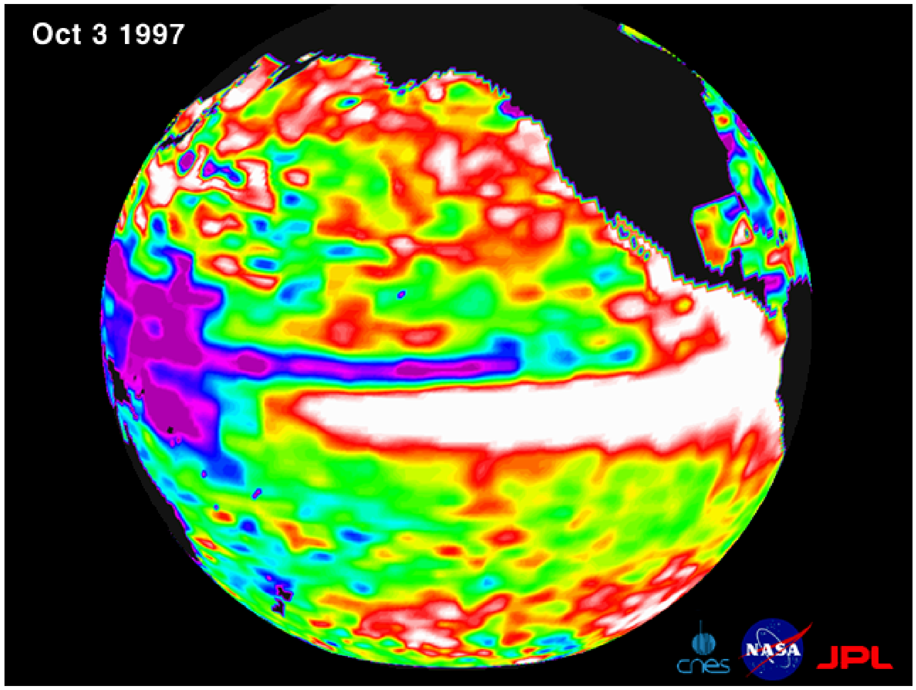
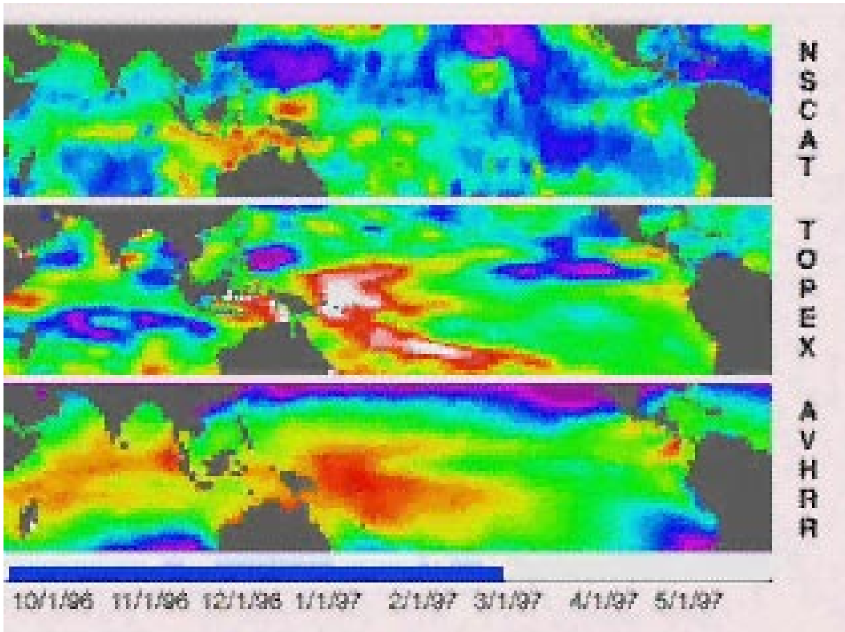


Figure 4. **El Niño conditions in the Pacific Ocean**. This view of the Pacific Ocean shows sea surface height relative to normal conditions during October 1997. The white and red areas indicate unusual patterns of heat storage. In the white areas, the sea surface is between 14 and 32 centimeters (6 to 13 inches) above normal. In the red areas, it's about 10 centimeters (4 inches) above normal. Green areas indicate normal conditions, while purple (the western Pacific) means at least 18 centimeters (7 inches) below normal. The surface area covered by the warm water mass is about one and one-half times the size of the continental U.S.

In non-El Niño years, trade winds blow westward along the equator and push surface water against Asia on the western side of the Pacific. The warm water evaporates and provides the necessary energy to drive circulation of the atmosphere and bring rain. The "pileup" of water in the west Pacific leaves lower sea level on the eastern side of the Pacific, which allows the upwelling of deep, cold, nutrient-rich water along the South American coastline, enriching the water with nutrients and leading to good catches for the local fishermen.

During an El Niño year, the trade winds weaken and reverse direction [Movie 1] along the equator. This change in winds allows a large mass of warm water that is normally located near Australia to move eastward along the equator until it reaches the west coast of South America [Fig. 4]. Off the coast of Peru, the upwelling of nutrient-rich is suppressed causing fish to go elsewhere, and leading to poor catches.



Movie 1. **Trade wind bursts.** This time-series of wind patterns in 1996-97 from the NASA Scatterometer (NSCAT) satellite show the trade winds blowing strongly westward in September 1996. This pushed warm surface water toward the western Pacific. In December, red areas near New Guinea indicate a “burst” of east-blowing winds. This reversal of trade winds allowed a pulse of warm water to move toward the Americas. Another larger (red) wind burst occurred in February 1997. This allowed warm water to travel eastward along the equator, and soon after, initiate a full-blown El Niño condition.

The displacement of so much warm water influences evaporation, alters where rain clouds form and, consequently, alters the typical atmospheric subtropical jet stream pattern around the world. Past El Niño events have often caused unusually heavy rain and flooding in the southwest U.S. and Gulf coast, unseasonably mild winters in the northern U.S., severe droughts in Australia, Africa, and Indonesia. Thus, improved predictions could help reduce the billions of dollars in damages caused by El Niño.

Hurricanes

Warm water currents are the source of the energy for one of the most destructive phenomena in nature: the *hurricane*. A hurricane is defined as a cyclonic (i.e., spinning) storm system with winds exceeding 119 km per hour (74 mi per hour) that are accompanied by heavy rains, and high waves [Fig. 5]. Such storms are called *typhoons* in the western North Pacific, and *cyclones* in the Indian Ocean. Hurricanes are one process by which the atmosphere transports heat from the tropics to mid-latitudes. Hurricanes can be thought of as heat engines that convert the warmth of tropical oceans and atmosphere into wind and waves.

Hurricanes near the United States occur almost exclusively off the east coast and in the Gulf of Mexico because of the presence of warm Gulf Stream waters. Warm water evaporates more readily than cooler water, thus the air above the Gulf Stream is very humid, especially in the summer months. As the humid air rises, it eventually cools and the vapor condenses into water droplets. The condensation releases *latent heat* stored in the humid air, providing energy to the developing hurricane. Before a hurricane can form, water temperature must be at least 27ºC (80ºF) to a depth of around 60 m (200 ft). If ocean currents change, and thus distribute heat differently, then the frequency of hurricanes can also change.

Category	Barometric Pressure	Winds	Storm Surge
Stage 1 **Minimal Damage:** Signs, landscape, power lines blown down	> 980 mb	74 to 95 mph 33-42 m/s	4 to 5 ft. 1.0-1.7 m
Stage 2 **Moderate Damage:** Bigger signs, tree branches, unsecured mobile homes	979-965 mb	96 to 100 mph 33-42 m/s	6 to 8 ft. 1.8-2.6 m
Stage 3 **Extensive Damage:** Pier damage, trees blown down, coastal flooding	964-945 mb	111 to 130 mph 33-42 m/s	9 to 12 ft. 2.7-3.8 m
Stage 4 **Extreme Damage:** Almost complete destruction to doors and windows & roofs	944-920 mb	131 to 155 mph 33-42 m/s	13 to 18 ft. 3.9-5.6 m
Stage 5 **Catastrophic Damage:** Structures, roofs & buildings destroyed; severe flooding	920 mb & less	> 155 mph 33-42 m/s	Higher than 18 ft. 5.6+ m

Figure 5. **Hurricane intensity scale**.

The tropical regions are the only areas that provide the key ingredients needed for hurricanes to form:

- large expanses of warm ocean water
- weak upper air winds that allow unrestricted vertical development from the surface to the upper *troposphere*
- latitude greater than 5°. This provides the minimum Coriolis force required to initiate rotation of the system.

Their formation is very dependent upon the water being warm enough, and so changes in ocean conditions that affect water temperature can either increase or decrease the formation of hurricanes. Hurricanes usually appear during a six-month period beginning late June, and reach their peak occurrence rate in mid-September as tropical water reaches its maximum temperature.

Figure 6. **Satellite image of hurricane Fran**. *Geostationary* Operational Environmental Satellites (GEOS-8) perspective view. Sept. 4, 1996.

Because of the *Coriolis effect*, air rotating around a low pressure center, such as that in the center of a hurricane, rotates counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. This initiates the typical spiral pattern associated with these storms [Fig. 6]. If Earth did not rotate, hurricanes would never form. Eventually the hurricanes dissipate either over water or land, generally in mid-latitudes, having transported heat from the equatorial regions to the mid-latitudes. The lifetime of a hurricane, from initial development as a small storm to dissipation, is typically between one and two weeks.

Hurricanes have been responsible for much death and destruction in the United States and the Caribbean. In the year 1900, six thousand people were killed when the storm surge associated with a hurricane struck Galveston, Texas. Today, weather satellites in Earth orbit can detect and track *tropical storms* as they develop into hurricanes, providing many hours warning of an impending hurricane. Many lives have been saved over the last few decades as a result of this technology.

Conclusion

Specific physical components of our climate interact to form one large system. For example, ocean and atmospheric circulation transport heat around the globe and affect regional climates. Year-to-year, seasonal, and short-term climate components such as El Niño conditions, monsoons, and hurricanes can affect our lives in very dramatic ways. To fully understand Earth's climate we need to study these types of ocean-atmosphere interactions. This knowledge may eventually forewarn us about long-term climate change, such as the approach of an ice age.

Vocabulary

Coriolis effect	*cyclone*	*El Niño*
geostationary	*global conveyor belt*	*Hadley cells*
heat capacity	*hurricane*	*ice age*
jet stream	*latent heat*	*monsoon*
salinity	*system*	*thermocline*
tropical storms	*troposphere*	*typhoon*
upwelling		